PROT. N.

THE MESOZOIC FLOOD VOLCANISM OF THE PARANÁ BASIN

petrogenetic and geophysical aspects

X.1. GRAVIMETRIC ANALYSIS OF THE GOIÂNIA FLEXURE, NORTHERN PARANÁ BASIN

P. SANTERO, M. ZADRO, D. BLITZKOW and N.C. de SÁ

E.M. PICCIRILLO
Istituto di Mineralogia e Petrografia
University of Trieste, Italy

A.J. MELFI
Instituto Astronômico e Geofísico
University of São Paulo, Brazil

Universidade de São Paulo
Instituto Astronômico e Geofísico
1988

X.1. GRAVIMETRIC ANALYSIS OF THE GOIÂNIA FLEXURE, NORTHERN PARANÁ BASIN

P. SANTERO, M. ZADRO, D. BLITZKOW and N.C. de SÁ

ABSTRACT: The Bouguer gravity anomaly data of the northern Paraná basin, Brazil, have been analysed, with particular regard to the Goiânia Flexure data. The Goiânia gravity data show a strong lineament which is localized along the N42°W direction. By filtering processes and by downward continuation the crust-mantle interface has been found to be at about 20 km when using a crust-mantle model characterized by a one-layer crust and a mantle with density values of 2.67 and 3.3 g/cm^3 respectively. The results have been also checked by direct modelling the discontinuity variations and by computing the corresponding surface gravity variations. As far as the whole northern Paraná basin is concerned, a more detailed analysis should be carried out in order to compute the terrain reduction and to take into account density variations of the surface rocks. Nevertheless, from the present preliminary analysis, the crustal thickness in the central flat part of the basin appears to be at least of 30 km.

INTRODUCTION

The gravity observations of the Paraná basin, Brazil, with particular regard to its NE part, are examined in this paper.

In order to have a general idea about the geological situation of the zone under consideration, we summarize, in a brief outline, the Paraná geological evolution (for further details about Paraná geology see Fúlfaro & Petri, 1983; Almeida, 1981; Mabesoone et al., 1981).

The Paraná basin is one of the intracratonic Brazilian basins and the lithological records of its evolution start, in Brazil, from the Devonian. At that time it was a site characterized by very active sedimentation, mostly developed in a marine environment. Its evolution, in quite a general way, can be described as a series of modifications which brought on the final effect of changing the marine environment to a continental one. The final change was completed at the end of the Paleozoic, when the basin was uplifted above the sea level and gained a morphological aspect similar to the present one. After the establishment of a continental environment, a period of tectonic tranquillity followed, while the sedimentation rates strongly decreased.

This situation lasted until the Upper Jurassic when a new series of tectonic activities led to the the so-called Wealdenian Reactivation connected with the events that brought to the opening of the Atlantic Ocean. An important volcanic activity, clearly linked with the tectonics, gave rise to two different magmatic stages, the former (Upper Jurassic-Early Cretaceous) characterized by a large amount of basaltic magmas produced in a lot of magmatic centers of the Paraná area (for instance the Ponta Grossa arch and its neighborhood and the Paraguayan arch), the latter (Upper Cretaceous) with quantitatively less important alkaline magmas.

The opening of the new ocean created a series of tectonic sedimentary basins near to the diverging margins. These will become the new sites of deposition, while the Paraná basin, located farther away from the activated area, faced a new reduction of the sedimentation rate and the prevalence of the erosional forces. In the north eastern parts of the basin the sedimentation processes continued for a longer time as they were due to a still working epeirogenic uplift, but approximately it's possible to say that at the beginning of the Tertiary, the whole Paraná was no longer an important sedimentation center.

Nowadays the basin is rather flat with stronger relief along its borders as it is bound by a series of archs some of which were active magmatic and tectonic centers during the Atlantic opening. The total thickness of the pre-lava sedimentary layers reaches, in the central part of the basin, 3500 m, while the overlying lava beds, that is material with higher density values, are about 1500 m thick where they reach their maximum thickness (Almeida, 1981; Almeida et al., 1981).

The analysis of the gravity data has been carried out with the main purpose of detecting the most likely depth of the crust-mantle discontinuity. The focus was on the NE part of the basin where a strong gravimetric lineament coinciding with the Goiânia Flexure was observed. It is important to note that the work was based only on gravity data as no other geophysical information was available as far as the Goiânia zone was concerned.

THE PARANÁ BASIN AND THE GOIÂNIA FLEXURE DATA

The data have been obtained from 7155 different stations along the whole Paraná basin. For each station, he geographical coordinates, the altitude, the observed ravity, the free air anomaly and the Bouguer anomaly without terrain correction, computed after the nternational Gravity Formula 1967, having a 2.67 g/cm^3 ensity) were available together with precision codes.

The data were collected by different Brazilian groups, amely by:

Geodesy and Gravity Group of Instituto Astronômico e Geofísico, São Paulo University (IAG/USP) which provided the largest amount of data. Their results are set up on the IBGE levelling network with mean distances of 3 to 6 km between stations. The gravity measurements were carried out using a LaCoste & Romberg (G model) gravitymeter and all the stations are referred to IGSN71 through the Brazilian Fundamental Gravity Network established by Observatório Nacional (Escobar, 1980).

nstituto Brasileiro de Geografia e Estatística (IBGE) contributed up to 30% of the total amount. Their data belong to a network built around the geodetic station of Chuá town (IBGE, 1984) and at first referred to the Potsdam system. In 1977, when a gravity network was stablished in the State of São Paulo, all these data were connected with the IGSN71 system (Blitzkow et ., 1978).

3) Observatório Nacional (ON): their share is up to 5% and is the topic of a special report (Gama, 1982).
4) Brazilian Oil Company (PETROBRÁS): they also with a 5% contribution.

Presently all the data are part of the IGSN71 network.

Due to the fact that we were not using the results of a single gravimetric survey, we had to face quite different accuracies and a quite irregular measurement distribution. Therefore the first step was to check the reliability of the data and then to select a more uniformly distributed data set. A first rough polynomial approximation was used, in order to delete values with unrealistic deviations from the local mean gravity distribution. In this way, data were deleted both in the case of stations and in the case of strong departures from neighboring observations, this operation led to the rejection of 140 stations. A second selection of data has been carried out by decimating highly concentrated swarm stations. Thanks to such a decimation the number of the data was reduced to 2103 without loss of information.

From now on we will call PA the domain referring to the northern part of the Paraná basin and GO the Goiânia area on which our work was mainly focused.

Both the PA and the GO gravity values have been suitably interpolated to obtain a new set of data corresponding to the nodal points of a square grid of 10 km side for PA and of 2.6 km for GO.

The area of the PA grid has geographic coordinates comprised between 18°-25°S and 57°-50°W, with an extension of 720 x 940 km. In that part of the basin both the sediments and the volcanic products of the two strong magmatic phases of the Wealdenian Reactivation reach the maximum thickness. The incomplete (without terrain reduction) Bouguer anomaly map (Fig. X.1) of the PA zone shows a weak relief without any significant or steep trend, if we disregard the borders and in particular the NE part where there are lower values and a quite sharp trend: this is the GO area. In the same figure the contour line of the 4000 m depth of the basement top (Ferreira, 1982) is also represented by a thick dashed line.

The GO area is located near northeastern border of the Paraná basin (see Fig. X.1), in the neighborhood of the Paramirim craton and between 50°-47°S approximately. The topographic relief ranges approximately from 350 to 1200 meters.

The terrain correction was computed for the GO gravity data by using a subroutine (Nagy, 1966a, b) which

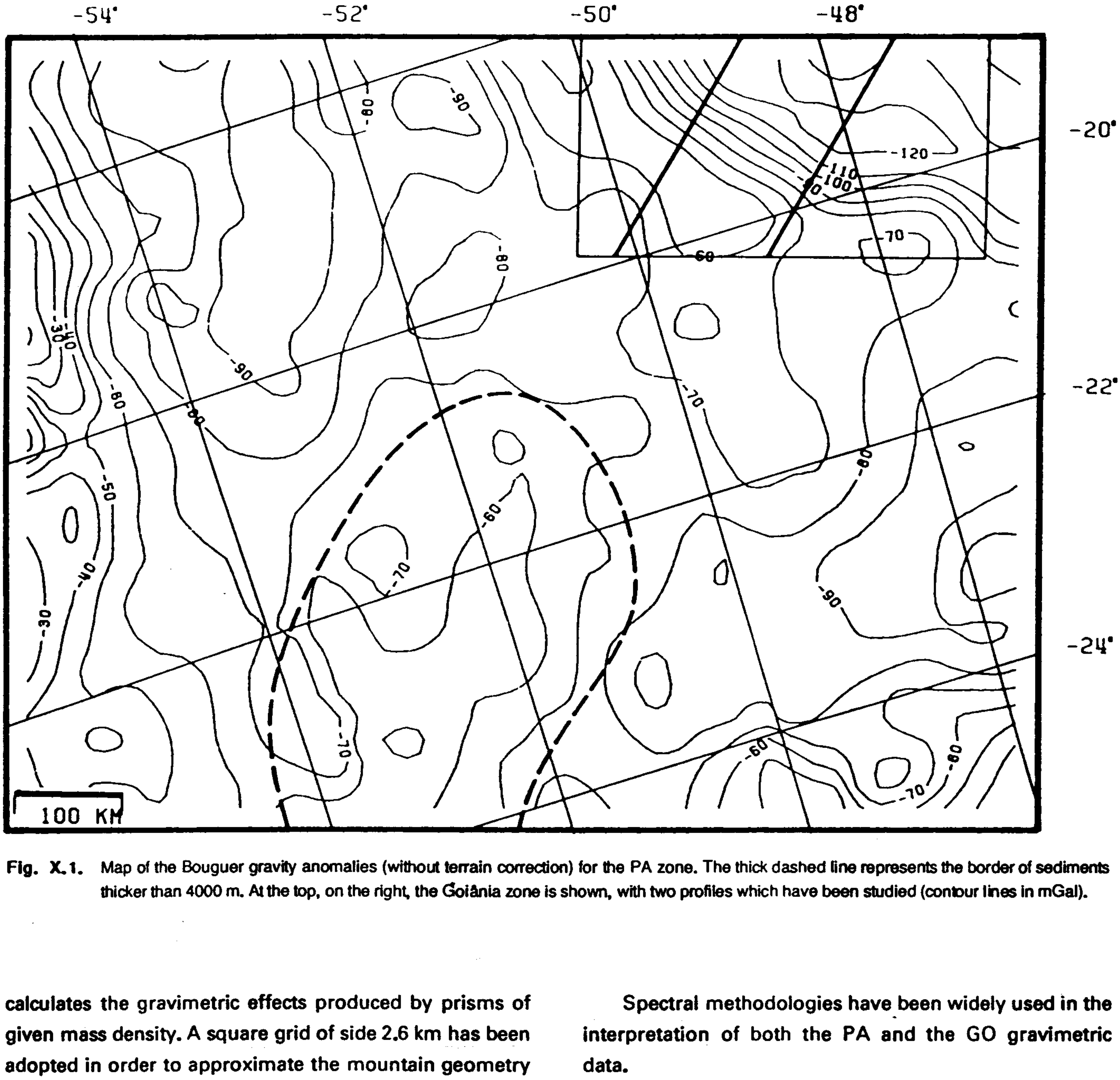

Fig. X.1. Map of the Bouguer gravity anomalies (without terrain correction) for the PA zone. The thick dashed line represents the border of sediments thicker than 4000 m. At the top, on the right, the Goiânia zone is shown, with two profiles which have been studied (contour lines in mGal).

calculates the gravimetric effects produced by prisms of given mass density. A square grid of side 2.6 km has been adopted in order to approximate the mountain geometry with prisms. The terrain correction, for each point, was calculated taking into account the gravimetric effects inside a circle of 30 km radius and for a density of 2.67 g/cm^3. Very small correction values have been obtained, with a maximum value of some miligals where the topography was the roughest. The map of the GO resulting Bouguer anomaly is represented in Fig. X.2. A detailed description of the data processing is given in Santero (1985).

2-D ANALYSES OF THE PA AND GO DATA

Filtering and downward continuation

Spectral methodologies have been widely used in the interpretation of both the PA and the GO gravimetric data.

Taking into account that the sampled arrays for both PA and GO have been obtained through interpolation processes which can fall at short wavelengths, the data have been low-pass filtered in the wavenumber domain. This spectral energies have been left unaltered up to 1/4 of the Nyquist wavenumber (wavelengths greater than 80 km for PA, 20 km for GO) and modulated by the D_2 Hamming window from 1/4 to 1/2 of the Nyquist wavenumber (wavelength between 80 and 40 km for PA and between 20 and 10 km for GO). Energies at wavenumbers higher than 1/2 of the Nyquist have been put to zero. Although the map of the PA filtered data did not show any significant difference with respect to the

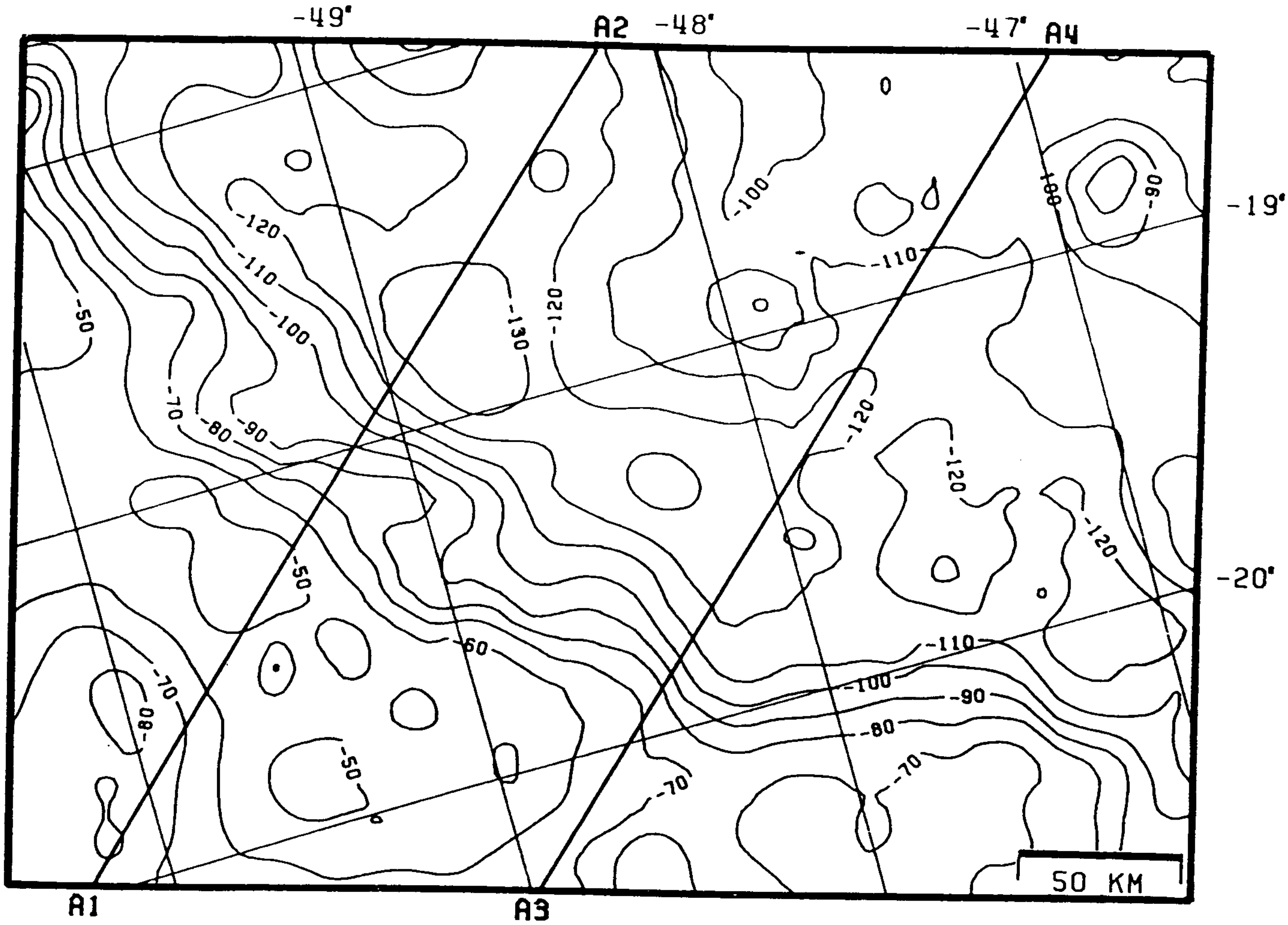

Fig. X.2. Map of Bouguer gravity anomalies for the GO zone with the A1-A2 and A3-A4 profiles (contour lines in mGal).

unfiltered data, the PA filtered data will be considered in the following computations, as being the more reliable.

For the GO case, where a lineament in the gravimetric data appears rather evident, the fan filter has been applied on the GO low-pass filtered data in order to evidence the lineament as well as its direction, and to filter out lateral perturbation effects. As it is well known, the fan filter, for a given direction θ and a given α fan opening angle, allows to extract structures aligned along directions $\theta-\alpha/2$, $\theta+\alpha/2$. In the actual case, with an α opening angle of 50^{o} the lineament orientation has been found to be at θ=N 42^{o}W. In Fig. X.3 that map of the GO fan filtered data is represented, having subtracted the mean value (-93.5 mgal). From now on the above GO fan filtered data will be considered as GO gravimetric data.

As the main purpose of the research was to inquire about the crust-mantle discontinuity, the downward continuation law has been considered as the more suitable tool for the interpretation, as well as low-pass filtering processes in order to avoid surface effects. The downward continuation was applied to the data having in mind a non-stratified crust with an average density of 2.67 g/cm^3 overlying a mantle having a density value of 3.3 g/cm^3.

Let us briefly summarize the downward continuation data processing (see e.q. Tsuboi, 1983, pag. 110-121). Starting from the Bouguer gravity anomaly g(x,y) at Z=0 the plane of measurements, its Fourier transform is given by:

1) $F(\alpha,\beta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(x,y)\exp(-2\pi i\,(\alpha x + \beta y))\,dx\,dy$

α and β being the coordinates in the transformed space.

At a downward-continued depth d the gravity anomaly g_d (x,y) is given by the following inverse Fourier

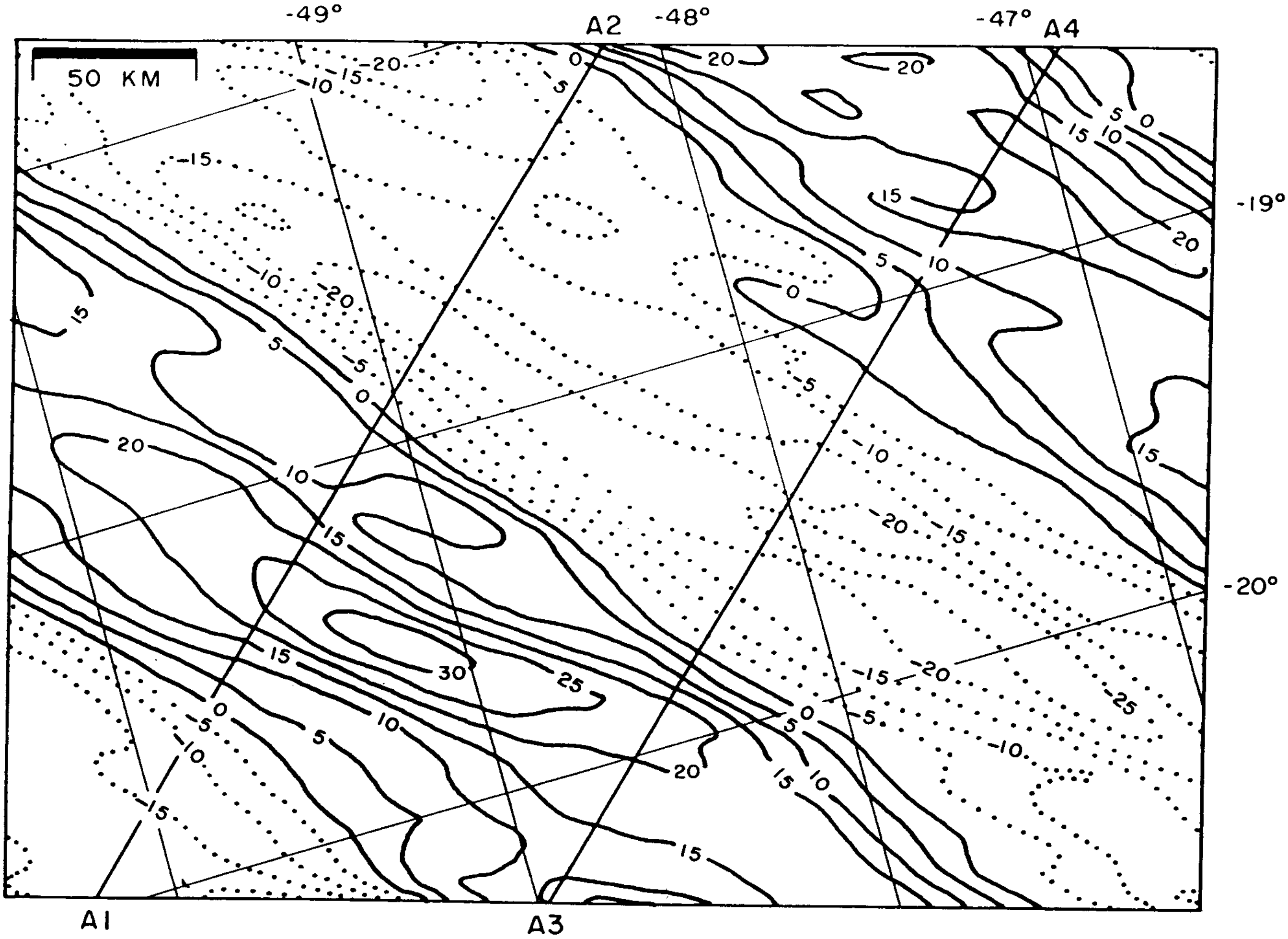

Fig. X.3. Map of the fan filtered Bouguer anomalies for the GO zone. Direction of the fan axis: N42°W (contour lines in mGal).

transform:

2) $g_d(x,y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F(\alpha,\beta) \exp(\sigma d + \pi 2i(\alpha x + \beta y))\, d\alpha\, d\beta$

where $\sigma = (\alpha^2 + \beta^2)^{1/2}$, $d > 0$ since Z is positive downwards.

The corresponding undulation $h(x,y)$ of the discontinuity interface supposed to be at depth d follows directly from (2):

3) $h(x,y) = g_d(x,y)/2\pi G r_o$

where $G = 6.67 \times 10^{-8}\ cm^3\ g^{-1}\ sec^{-2}$ is the Newtonian gravitational constant and r_o is the crust-mantle density contrast.

Since the undulation heights $h(x,y)$ greatly increase with d, becoming unrealistic when crossing the discontinuity, a criterion for finding d is to loop the computational steps from (1) to (3) for an assigned fixed r_o value but for progressively increasing values of d and to check the undulation variations.

Surface and small size perturbing masses contribute to high wavenumber energies and this contribution increases with depth. In this analysis, suitable low-pass filters have been applied at step (2) depending on the downward continuation depth d in order to avoid, as much as possible, shallower effects.

The above methodology has been applied to both the PA and the GO gravity data for several values of depth d. The maps of interface undulations are given for depths of 20 and 30 km for both the PA and the GO data (Figs. X.4-X.6 for PA, X.7 and X.8 for GO). The contour line notations are in hundreds of meters for $r_o = 1$. Being 2.67 g/cm^3 the crust density and 3.3 g/cm^3 the mantle one, the density contrast for the crust-mantle discontinuity will be $r_o = 3.3 - 2.67 = 0.63$ g/cm^3. Therefore, in order to get the actual heights (along the interface), the contour line notations have to be divided by such a value (formula (2)). It is important to note that a reasonable depth for the discontinuity depends on the density contrast value. Namely, lower density contrast will make the topography rougher, giving unrealistic results at shallower levels. Short cut-off wavelengths were chosen for filtering in order to destroy, as much as possible, signal energies in the downward continuation process. The results of the downward continuation which are presented in Figs. X.4, X.7 and X.8 have been obtained by adopting a single cut-off wavelength of 60 km.

The PA area

As far as the PA zone is concerned, a more detailed analysis should be carried out taking into account both the strong sub-surface density variations and the terrain gravity correction. These effects surely play a significant role at the border of the zone as can be judged by looking at the strong and unrealistic variations occurring there in both the 20 and 30 km continuations (Figs. X.4 and X.5). Nevertheless, some preliminary considerations can be made at least about the central part of the basin. In that zone, the available Bouguer anomaly data are reliable also without terrain reductions due to the flat topography. The wide horizontal structures of sedimentary and basaltic rocks seem to compensate each other from the gravimetric point of view thus giving slightly varying surface effects as judged by looking at the Bouguer anomaly (Fig. X.1) and comparing it with the

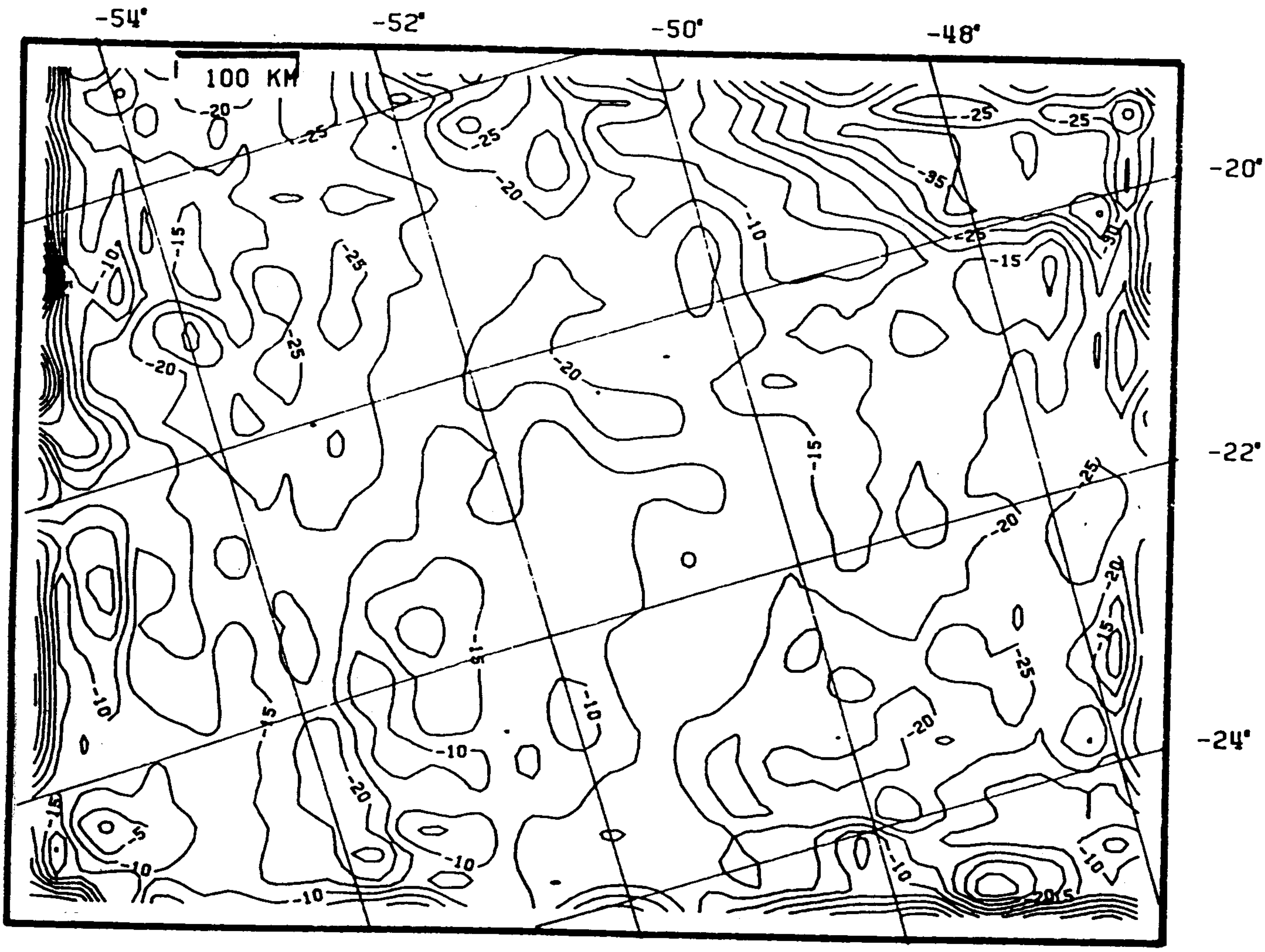

Fig. X.4. Map of the PA interface undulations at 20 km depth downward continuation. Cut-off wavelength LC = 60 km. The height values have to be divided by the density contrast r_o in order to get the heights in hundreds of meters.

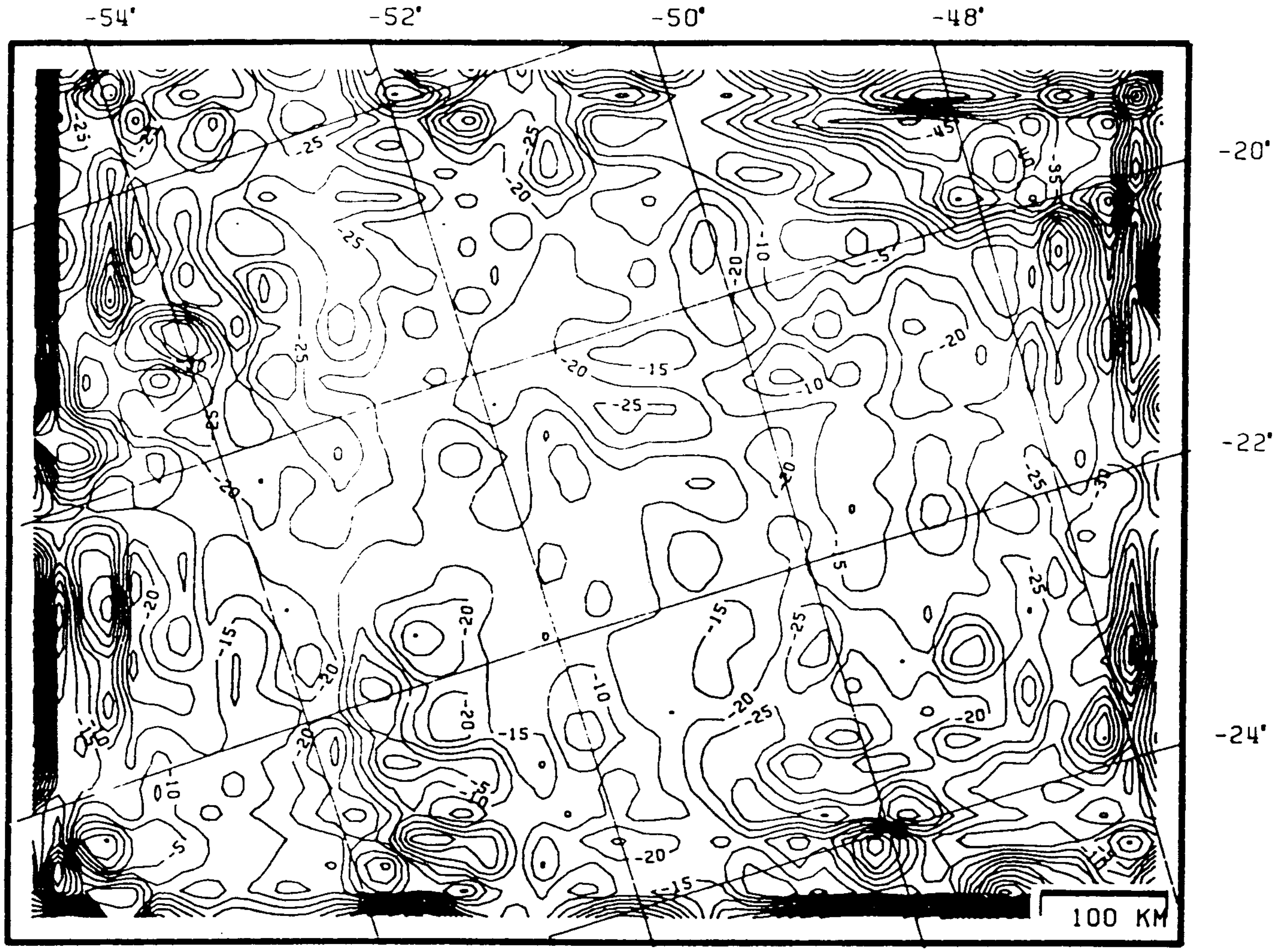

Fig. X.5. Same as Fig. X.4 for 30 km depth downward continuation.

sedimentation zone.

In the downward continuation, moderate "jumps" appear in the PA inner zone only for depths greater than 30 km, as can be judged by comparing Figs. X.4 and X.5. By taking into account that the isoline notations of Fig. X.5 have to be divided by a presumable value of density contrast of 0.63, very feeble height undulations occur at the 30 km depth. Thus it can be concluded that a depth of at least 30 km can be accepted in that zone as a reliable mean depth for the crust-mantle discontinuity.

In order to better visualize the crust-mantle large geometrical structures of the PA zone avoiding surface effects as well as deep small-size effects, the 30 km continuation map has been produced by filtering out short wavelength effects up to wavelengths of 200 km (Fig. X.6). The interface appears nearly flat in a very wide inner part of the zone.

The GO area

The lineament is situated at the northeastern border of the Paraná basin. In shallow continuations (a few kilometers) feeble opposite-sign surface density variations have been detected in alternating narrow strips parallel to the lineament, thus indicating the presence of alternating surface density discontinuities associated with sediments and basalts. These effects have been deleted by the filtering process adopted.

The 20 and 30 km continuations are represented in Figs. X.7 and X.8. Large strips of about a hundred kilometers wide with alternating positive and negative values, occur parallel to the lineament in the 20 km downward continuation. In the 30 km continuation instead, these appear overlapped and masked by sharp shorter wavelength effects. On the basis of these results,

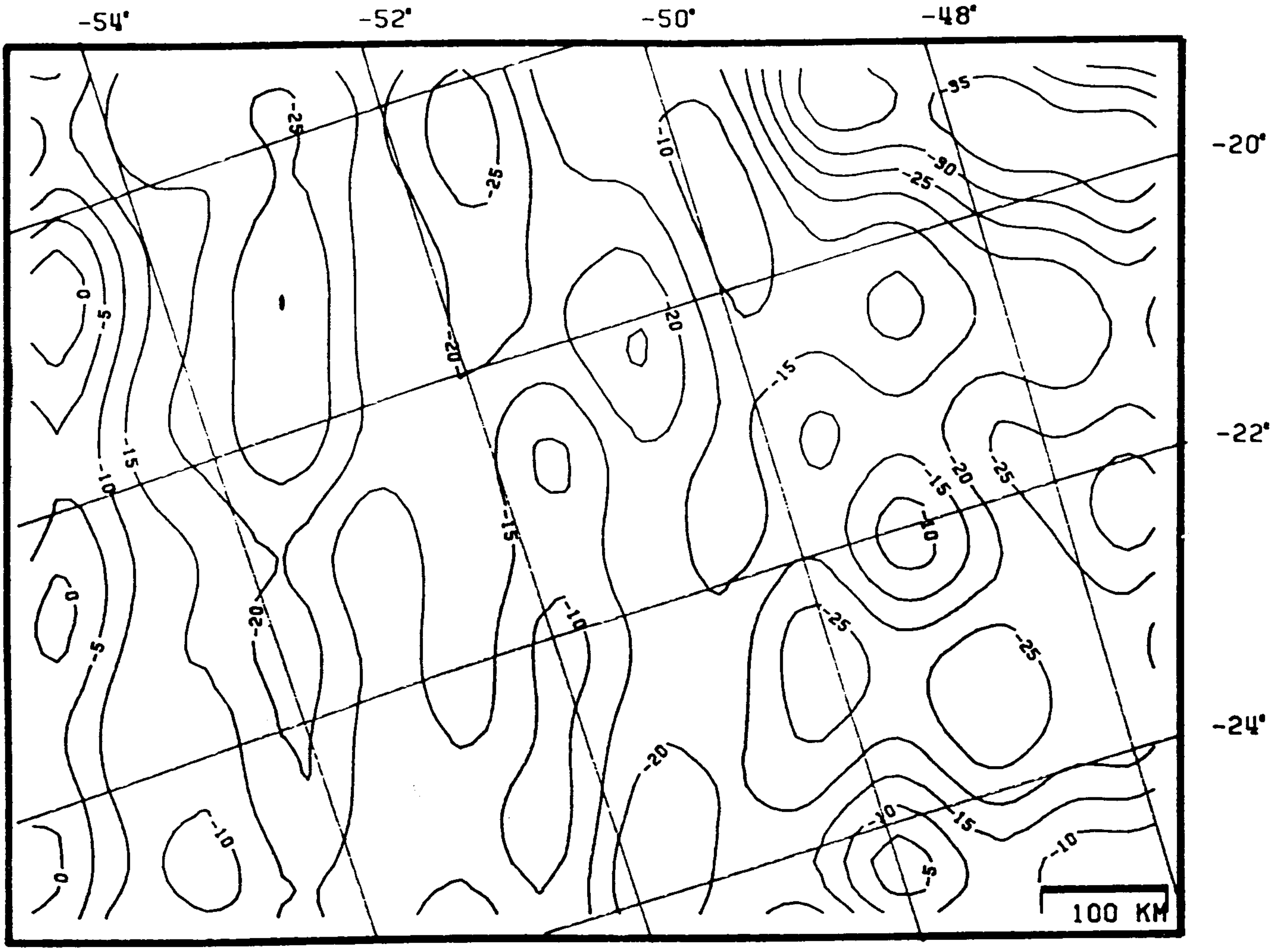

Fig. X.6. Same as Fig. X.5 for cut-off wavelength LC = 200 km.

the 20 km depth appears to be the most reliable depth for the GO crust-mantle interface in the hypothesis of a one-layer crust overlying the mantle.

1-D ANALYSES OF THE GO DATA

Two profiles (A1-A2 and A3-A4) orthogonal to the GO lineament have been considered for detailed analyses. The crust-mantle depth variations for $r_o = 0.63$ have been numerically calculated along the A1-A2 and A3-A4 profiles from the 2-D data obtained for the 20 and 30 km continuations and plotted in Figs. X.7-X.8. Analogously the corresponding Bouguer anomaly profiles have been obtained from the 2-D fan filtered data of the GO zone, plotted in Fig. X.3.

The gravity perturbation effects produced by an infinitely long cylindrical structure have been computed, the cross-section of the structures being the topographic crust-mantle relief inferred by the continuation law at 20 and 30 km respectively. The density of the cylindrical structure has still been taken as 0.63 g/cm^3. The spectral methodology adopted (Zadro, 1984; 1986) allows to achieve, using a fast computer technique, accurate values of the gravitational effect in a very wide space range from the bottom of the structure to and beyond the observational surface. The cases analysed are represented in Figs. X.9-X.12. In these plots the first curve from the top represents the 'observed' fan-filtered gravity anomaly. The second and the third curves represent the computed response, at the geoidal surface and at 4 km below it, caused by the discontinuity relief shown at the bottom of the figures.

The downward continuation, as well known, squeezes the perturbing mass on the plane assumed for

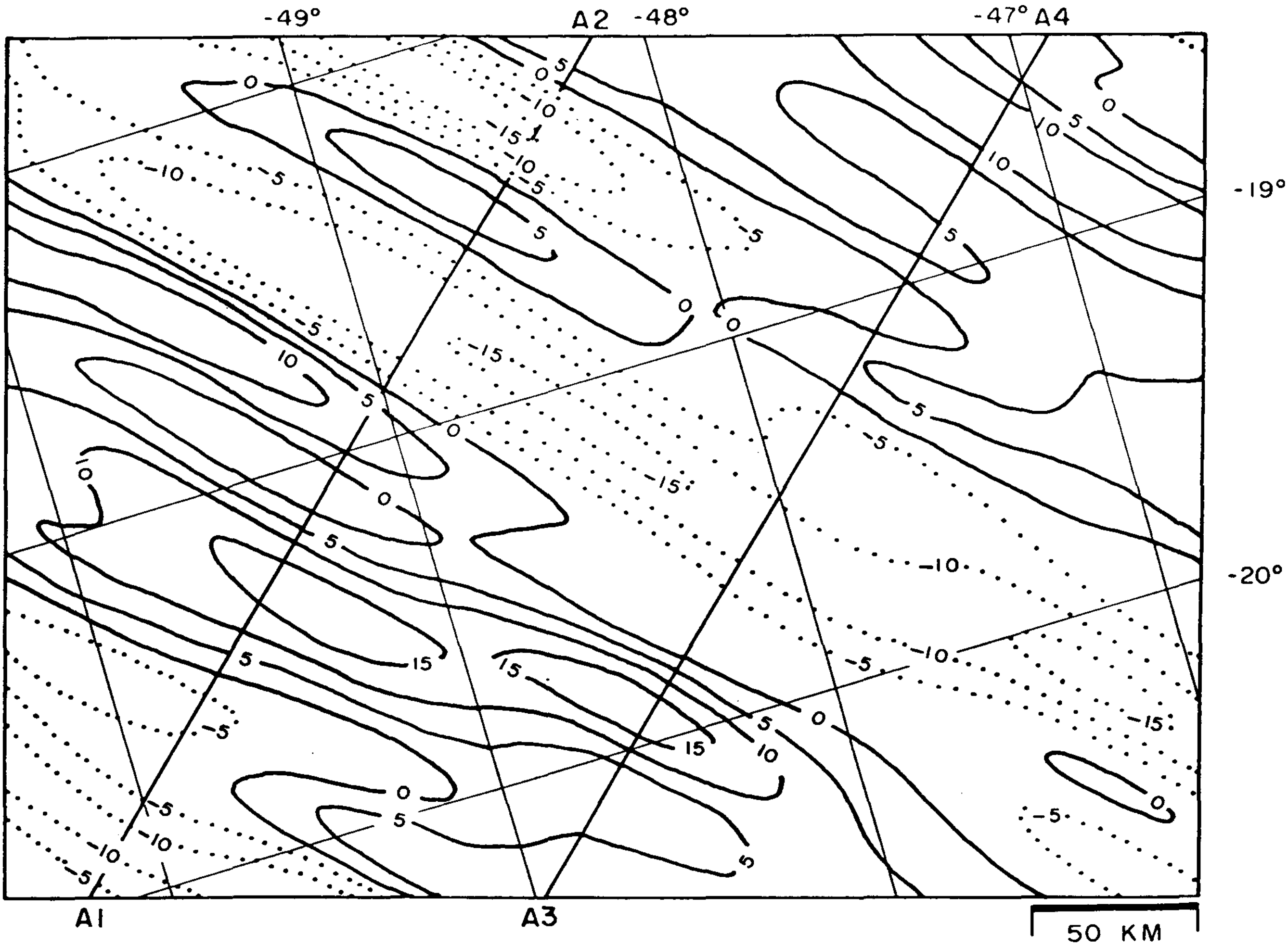

Fig. X.7. Map of the GO interface undulations at 20 km depth downward continuation. Cut-off wavelength LC = 60 km. The height values have to be divided by the density contrast r_0 in order to get the heights in hundreds of meters.

the continuation so that the actual geometry of the mass can only be inferred from formula (2). Due to the great depth of the structures considered, the computations, which have been carried out taking into account the geometrical shape obtained from formula (2), give gravitational effects at the surface which fit quite well the observations in all four cases considered (20 and 30 km for both profiles) as can be seen in Figs. X.9-X.12. Moreover it results, that the filtering used in the continuation process did not alter any significant property of the model.

Looking now at the crust-mantle interface undulations, the steep variations occurring in the 30 km case stress the exclusion of such a hypothesis as already suggested in the 2-D analysis. The 20 km hypothesis instead appears to be the most reasonable one.

CONCLUSIVE NOTES

The main aim of the research was the interpretation of the gravity anomaly lineament of the Goiânia (GO) region. In this area, surface effects are rather negligible if compared with those of the whole northern Paraná basin (PA), since here the sedimentary layers and magmatic materials are thinner than in the inner part of the basin (see the maps of the thickness of different formations and the one of the depth of the basement in Almeida 1981 and Ferreira, 1982). In the downward continuation at shallow depths, some sedimentary and magmatic products gave rise to alternating narrow strips parallel to the lineament resembling a subvertical sequence of distribution. Through filtering processes these contributions were eliminated in order to highlight deep structure features.

It appears, both from the continuation law results (Figs. X.7-X.8) and from forward gravity modelling (Figs. X.9-X.12) that the crust-mantle discontinuity has to be

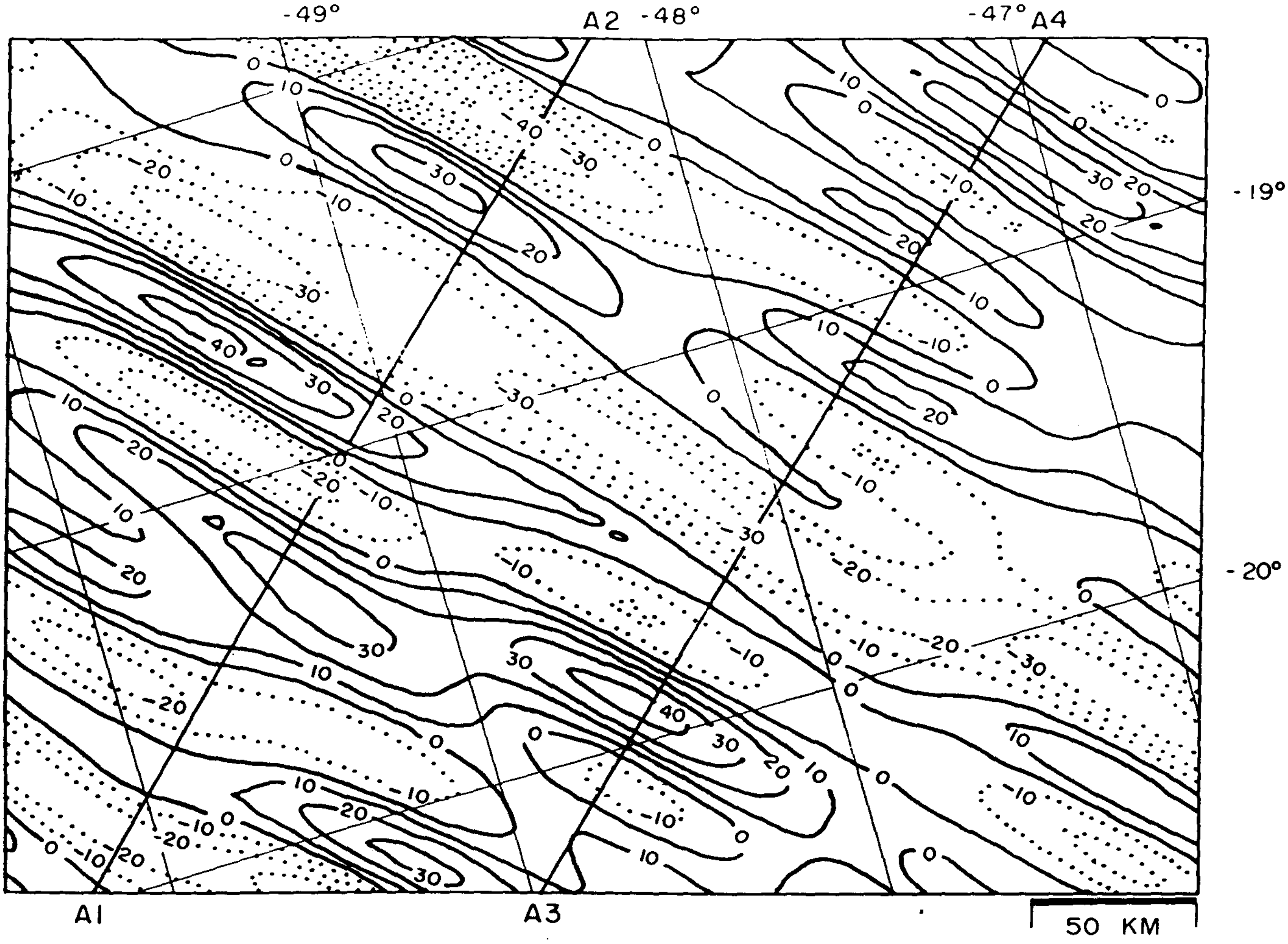

Fig. X.8. Same as Fig. X.7 for 30 km depth downward continuation and cutt-off wavelength 60 km.

shallower than 30 km along the Goiânia lineament. Also filtering out short wavelengths, the high oscillations of the 30 km discontinuity topograhy (Figs. X.9 and X.10) appear unrealistic. The 20 km downward results give instead acceptable variations in the crust-mantle interface and this solution appears much more reasonable. The correspondence between the observed and the computed values is quite good. Of course, since no other geophysical information was available in that zone, only a single vertical density variation was assumed but it is presumable that more complex structures occur, so that the present one can be accepted as a first approximation. It has to be noted that the values considered in the GO analysis have zero-mean value. The mean value being of -93.5 mgal, a broad wavelength discontinuity can still be argued to exist in the lower crust or in the upper mantle.

As far as the whole northern Paraná basin (PA) is concerned, a more detailed data treatment should be carried out. The terrain correction is needed, especially at its borders where the topography is rougher. Moreover, there the density of the surface rocks varies and such variations should be taken into account in further analysis. On the other hand, in the whole central part where the topographic level is almost flat and the observed Bouguer anomalies could be considered without terrain corrections, correction for the large amount of sediments and basalt layers should instead be considered. The actual situation, disregarding the borders of the basin and supposing a balance between negative and positive gravitational effects of the sediments and the basaltic beds, shows that a very flat crust-mantle interface can occur at 30 km of depth and perhaps even at a deeper depth. The relief is well mapped in Fig. X.6 where a very large cut-off wavelength has been adopted in order to make evident only very broad structures of the interface.

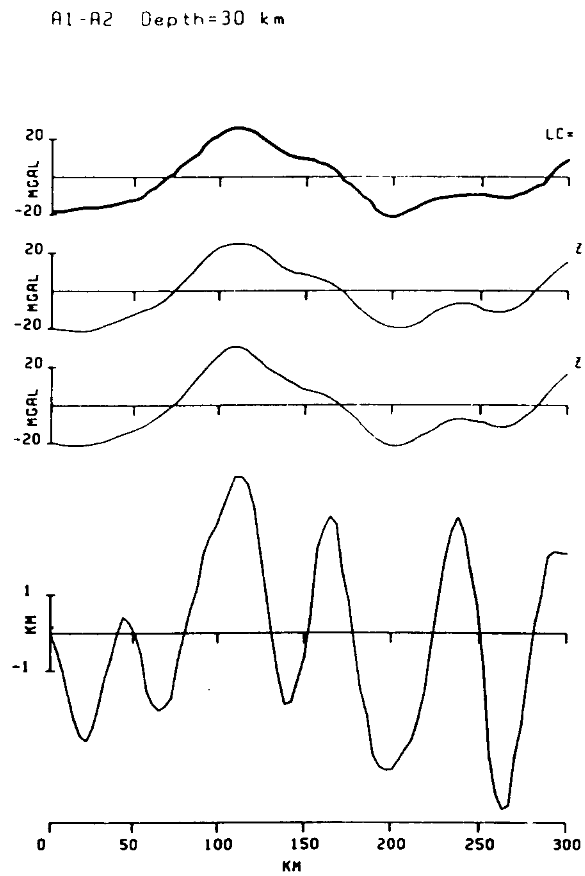

Fig. X.9. The A1-A2 profile across the Goiânia lineament. The first curve from the top represents the Bouguer observed anomaly. The second and third curves show the complete gravitational effects produced at the surface and 4 km below it by the crust-mantle undulation represented at the bottom for a mean depth of 30 km and for a density contrast 0.63 g/cm^3.

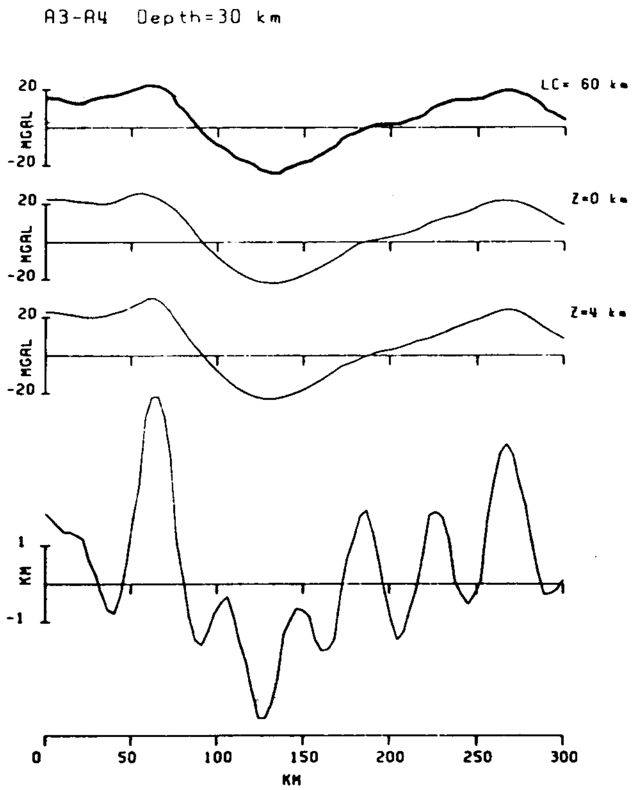

Fig. X.10. Same as Fig. X.9 for the A3-A4 profile.

A comparison with the results obtained from analysis carried out in neighbouring areas might be interesting.

Within the São Francisco craton, Corrado et al. (1978) and Blitzkow et al. (1980) have proposed a two-layers gravimetric model using seismic data of Giese & Schütte (1975). The crust-mantle depth was found to be at 38-40 km.

Another work (Lesquer et al., 1981) which made use of gravity data focused on a nearby and partially overlapping area (latitude 17°-19°S; longitude 49°-44°W). These authors have interpreted the observed linear gravity feature (GO area), which parallels the southern border of the São Francisco craton, as caused by a lateral density and thickness variation from a thicker (~ 40 km) São Francisco craton towards a thinner (~ 35 km) and relatively denser crust under the Paraná basin.

If the crust in the GO area is thicker than that estimated (20 km) from the downward continuation process used in the present work, than it would be necessary to find an alternative model to explain the "jumps" in the crust-mantle interface (Figs. X.9-X.10) shown in the 30 km downward continuation results. The long wavelength anomalies in the inner part of the PA basin (Fig. X.6) show a privileged direction which is perpendicular to the one found at GO area, thus supporting the hypothesis of the existence of a tectonic sub-horizontal stress field with principal axes directed according to the lineaments. The first axis - of compression - could be responsible for the PA deep structure bending, whereas the second one - of tension - could have created tensile parallel fractures at GO with subsequent ascending of mantle "dike-like" intrusions.

A second hypothesis which could partially explain the "jumps" observed in the present analysis, between the GO and the PA crustal thickness, regards the possible presence of a lower crust layer intruded with mantle materials. Both hypothesis should be taken into account in a further analysis, with the help of more geophysical data - mainly seismic data across the GO-PA structure.

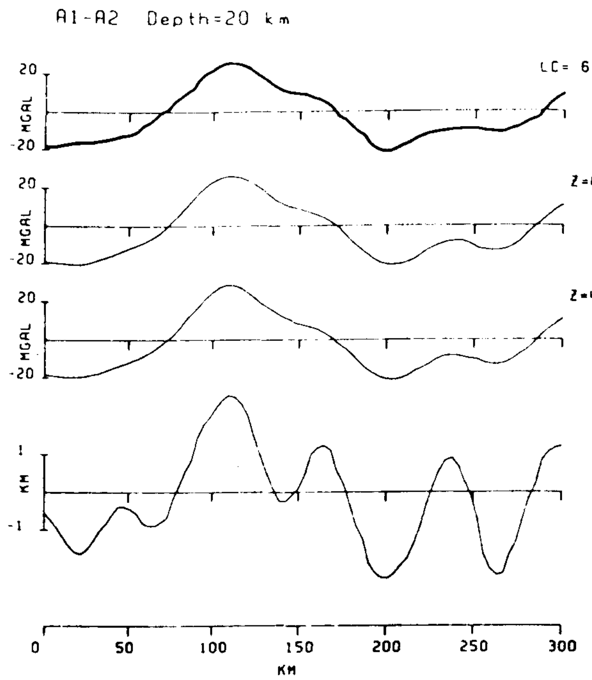

Fig. X.11. Same as Fig. X.9 for the mean depth of 20 km.

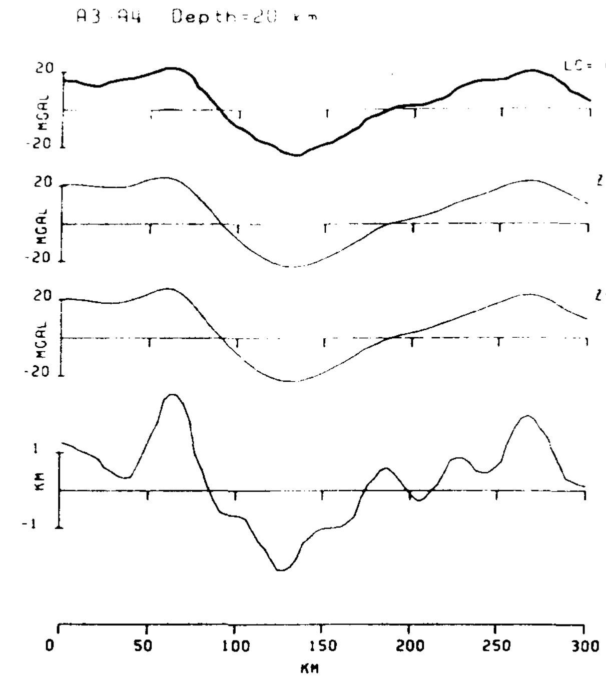

Fig. X.12. Same as Fig. X.9 for the A3-A4 profile and a mean depth of 20 km.

ACKNOWLEDGEMENTS

The authors thank Prof. C. Ebblin for his many valuable suggestions about the geological-geophysical interpretation of the Goiânia deep structure and Dr. N. Ussami for her observations and critical reading of the manuscript.

Research carried out with funds MPI 40% R85 2/12/2 6HO and MPI 60% R85 2/12/1 6HO, contractor M. Zadro.

REFERENCES

ALMEIDA, F.F.M., 1981. Síntese sobre a tectônica da bacia do Paraná. Atas do 3º Simpósio Regional de Geologia, SBG/SP, 1, 1-20.

ALMEIDA, F.F.M., HASUI, Y., BRITO NEVES, B.B. de, FUCK, R.A., 1981. Brazilian structural provinces: an introduction. Earth Sci. Rev., in: Mabesoone, J.M., Brito Neves, B.B. de, Sial, A.N. (eds.), The Geology of Brazil, XVII, 1-19.

BLITZKOW, D., SÁ, N.C. de, 1978. Rede gravimétrica fundamental do Estado de São Paulo. XXX Congresso Brasileiro de Geologia, Recife - PE.

BLITZKOW, D., GASPARINI, P., MANTOVANI, M.S.M., SÁ, N.C. de, 1980. Crustal structures of the southeastern Minas Gerais, Brazil, deduced from gravity measurements. Rev. Bras. Geoc., 9, 39-43.

CORRADO, G., RAPOLLA, A., GASPARINI, P. and MANTOVANI, M.S.M., 1978. Depth of Curie temperature from aeromagnetic anomalies in southeastern Minas Gerais, Brazil. Rev. Bras. Geoc., 9, 33-38.

ESCOBAR, I.P., 1980. Métodos de levantamento e ajustamento de observações gravimétricas visando a implantação da Rede Gravimétrica Fundamental Brasileira. Observatório Nacional, Rio de Janeiro, Publ. no. 1, 57 pp.

FERREIRA, F.J.F., 1982. Integração de dados aeromagnéticos e geológicos: configuração e evolução tectônica do Arco de Ponta Grossa. MSc. Thesis, São Paulo Unversity, Brazil.

FÚLFARO, V.J., PETRI, S., 1983. Geologia do Brasil. Editora da Universidade de São Paulo, São Paulo.

GAMA, L.I., 1972. Valores de gravidade nas regiões centro e sul do Brasil. Observatório Nacional, Rio de Janeiro, Publ. Serv. Grav., no. 4, 78 pp.

GIESE, P., SCHÜTTE, J., 1975. Preliminary report on the results of seismic measurements in the Brazilian coastal mountains. Unpublished report, Freiburg

University.

IBGE (Instituto Brasileiro de Geografia e Estatística), 1964. Relação de estações gravimétricas do DATUM geodésico. Divisão de Geodésia e Topografia (unpublished data).

LESQUER, A., ALMEIDA, F.F.M. de, DAVINO, A., LACHAUD, J.C., MAILLARD, P., 1981. Signification structurale des anomalies gravimetriques de la partie sud du craton de São Francisco, Bresil. Tectonophysics, 76, 273-293.

MABESOONE, J.M., BRITO NEVES, B.B. de, SIAL, A.N. (Eds.), 1981. The geology of Brazil. Earth Sci. Rev., XVII, 1-2.

NAGY, D., 1966. The prism method for terrain corrections using digital computers. Pageoph., 63, 1, 31-39.

NAGY, D., 1966. The gravitational attraction of a right rectangular prism. Geophysics, XXXI, 2, 362-371.

SANTERO, P., 1985. Anomalie gravimetriche nel Paraná. Unpublished thesis, Trieste University, Italy.

TSUBOI, C., 1983. Gravity. Allen & Unwin, London.

ZADRO, M., 1984. Spectral properties of the Newtonian potential field and their application in the interpretation of the gravity anomalies. Geophys. J.R. astr. Soc., 79:2, 489-494.

ZADRO, M., 1986. Spectral images of the gravitational field. Manuscripta Geodaetica, 11: 207-213.